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A METHOD OF REDUCING THE MASS OF PENETRATING WARHEADS

by

M. J. Twigger

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A METHOD OF REDUCING THE MASS OF PENETRATING WARHEADS

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M. J. Twigger

SUMMARY

A method of reducing the mass of a concrete-penetrating weapon by use of an elongated solid nose is presented, giving a mass reduction of 75% in the case considered when compared with a conventionally shaped warhead. The effect of varying the impact velocity is also discussed.

The technique is not necessarily applicable to all penetrating weapons, or to all targets. Each particular case has to be considered separately, since there is no general rule.

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CONTENTS

1 INTRODUCTION

A recent feasibility study was concerned with an air-dropped weapon intended to crater concrete and also one which would pass through a concrete wall. In the first case, it was required to make a crater of specified diameter with a weapon having a specified impact velocity. All other parameters were variable. It was required to minimise the total weapon mass. In the second case, the object was to place a specified amount of HE on the far side of a concrete wall of known thickness. Again the minimum mass weapon was required.

The parametric study showed that the mass of a conventional concrete piercing weapon could be reduced by optimising impact velocity in conjunction with use of a solid elongated nose on the warhead. Since the fixed impact velocity cratering weapon was the major interest of the feasibility study most work has been done on, and the Report is mainly concerned with, this weapon. However, the effect of variation in impact velocity on the mass of a crater forming weapon has been touched on. The application of the method to a wall piercing weapon has been covered in less detail than the cratering weapon.

In section 2 the two methods of reducing warhead mass are discussed in detail, followed in section 3 by examples of mass savings possible. Section 4 outlines the pros and cons of an elongated nose and of raising impact velocity by using a rocket booster. The Appendix gives the design rules used to determine warhead and rocket configurations.

2 METHODS OF DECREASING WARHEAD SIZE

The method of designing the warhead is explained in the Appendix. Once the impact velocity is fixed, the HE chamber configuration and case thickness (and thus outer diameter and amount of HE) can be calculated. Further equations allow determination of the penetration and crater diameter. The addition of a solid elongated nose does not alter the HE chamber dimensions, only the mass and thus penetration.

Looking first at a weapon designed to produce a crater, Fig.1 shows the crater diameter resulting from a charge detonated below the surface. For a given charge there is an optimum depth which gives a maximum crater diameter, or conversely for a given crater diameter detonation at the optimum depth gives a minimum HE charge. At the optimum depth, since the total mass of a warhead is approximately proportional to the charge mass, the total warhead

mass will also be low. However, because the factors of warhead strength and penetration enter into the optimisation procedure, the minimum mass warhead will not necessarily be designed to detonate at this optimum depth.

The penetration of a projectile into concrete is approximately proportional to MV/D^2, where M is the mass, V the impact velocity and D the diameter. The exact relationship is shown in the Appendix to this Report, equation (6). The penetration can be increased by raising either the M/D^2 ratio or the impact velocity, or both. The effect of increasing V is looked at briefly in the next section; it is the M/D^2 ratio which is main concern of this Report.

If a cratering weapon nose is elongated, the M/D^2 is increased. Fig.2 shows the idealised warhead with an elongated solid nose compared with a conventional warhead. The higher M/D^2 results in increased penetration of the HE, allowing the HE amount to be reduced, which in turn leads to a reduction in diameter, thus further increasing the M/D^2 ratio. The improvement is halted by the fact that whereas the M/D^2 ratio affects penetration of the extreme nose of the warhead, it is the penetration of the HE that matters, and there comes a point where the increase in solid nose length balances the increase in nose penetration thus leaving the HE at the same depth. There is therefore an optimum solid nose length at which the warhead mass is a minimum.

In the case of a weapon designed to pierce a concrete wall, holding a specified amount of HE, the size of the warhead is determined by the HE amount and the unaided impact velocity resulting from the means of launching the weapon. The diameter is substantially dictated by the HE amount specified. Thus the use of a solid nose simply adds to the warhead mass, rather than reducing it, since the reduction process described in the previous paragraph cannot occur because of the fixed HE mass. If the warhead of conventional form has a sufficient impact velocity, then its mass cannot be reduced by adding a solid nose. On the other hand, if it is incapable of piercing the wall due to a low unaided velocity, then the MV/D^2 ratio must be raised. The usual method is to incorporate a rocket booster (it being assumed here that the velocity increment cannot be provided by the weapon launcher or gun). However, the mass of the rocket rises in an exponential manner with velocity increment increase, and for hard targets the total weapon mass could be much higher than the warhead alone. In such cases the addition of an elongated solid nose can be of use in reducing the mass. The M/D^2 ratio is increased which permits a

reduction in velocity increment required and hence rocket mass. This effect gives a minimum mass weapon at the optimum values of solid nose length and rocket size. It must be pointed out, however, that the reductions possible depend on the target, and weapon unboosted velocity and HE amount. It might not be possible to obtain reductions at all in some cases.

The general effect of varying impact velocity between V_1, the unboosted velocity, and V_2, the velocity needed to pierce the wall with no solid nose, is shown in Fig.3.

3 EXAMPLES OF POSSIBLE SAVINGS

In order to give an idea of the magnitude of mass reduction possible by optimising the solid nose length, a typical example has been worked through.

A specified impact velocity of 427 m/s and a required crater diameter of 1 m have been taken. The fuze was assumed to have a mass of 40.8 g and a volume of 23.15 cm^3. A nose ogive radius of 2.5 calibres and an HE chamber ogive radius of 4 (1.4 for the conventional warhead with no solid nose), a steel dynamic yield strength of 1544 MN/m^2, a concrete compressive strength of 44.8 MN/m^2 and aggregate size of 19.1 mm, and a projectile angle of yaw at impact of 5^o were assumed. For the purposes of the exercise no design safety factors were employed, the velocity used to calculate penetration being taken as the same as the theoretical failure impact velocity of the warhead. This assumption, made for convenience of calculation, does not affect the general conclusions.

Using the methods outlined in the Appendix, Fig.4 was produced. This shows the variation in total warhead mass and length with the solid nose length ℓ/D (expressed in calibres). Five of these warheads are drawn to a common scale in Fig.5. The minimum mass occurs at $\ell/D = 8$ and the minimum length at $\ell/D = 5$. Clearly, the reduction in mass possible using the solid nose technique is considerable.

Even larger reductions can be achieved by using a rocket booster, bringing the total mass down to just under 1 kg minimum at an impact velocity of 870 m/s in the example considered.

In the case of warheads for piercing concrete walls, Fig.3 indicates the general effect of optimising impact velocity and solid nose length for a given amount of HE. This example has not been worked out fully and numbers are not shown for this reason. Penetration for this weapon is constant,

unlike the crater forming type. The velocity V_1 represents the unboosted velocity of the warhead. V_2 is the velocity at which the basic warhead, with no solid nose, will penetrate the required distance. Rocket size was calculated using equation (7) of the Appendix. At velocity V_1, a large solid nose is required but no rocket. As the velocity is raised by an increasingly large rocket, the solid nose length required for penetration and hence warhead mass can be reduced. The addition of the rocket mass and warhead mass gives a weapon mass which has a minimum value at a velocity between V_1 and V_2. Here again, savings appear worthwhile. However, mass reduction cannot be achieved for all weapons designed to pierce concrete walls, as it usually can be in the case of the cratering weapon, and in some cases no gains at all can be made. Each new application must be considered afresh.

4 ADVANTAGES AND DISADVANTAGES OF AN ELONGATED NOSE

As has been pointed out, the minimum mass weapon for cratering is obtained by using a rocket booster. There may, however, be objections to the use of a rocket. For instance, development costs or time could be too high, or there may be unacceptable impact point errors due to ignition when the projectile is yawing. In such cases the use of a solid elongated nose offers a method of reducing the mass of a conventional warhead to near the minimum value possible using a rocket.

As Fig.5 shows, there are gains in both mass and length resulting from a solid nose being applied to a cratering weapon. The top sketch shows the conventional warhead.

In the case of a wall-piercing warhead, mass reduction will not always be possible. Where it is possible, both an elongated nose and a rocket booster will usually be needed to achieve minimum mass, although there may be cases where a solid nose alone might be sufficient. In the event that a rocket booster is undesirable, a solid nose offers the only way of achieving the objective of penetrating the wall.

Turning to the disadvantages, the first objection must be the slenderness of the warhead. Trials[4] with inert rounds indicate that a weapon similar to that shown in Fig.5 with a solid nose length of 5 calibres (actual length was 6.2 calibres) was strong enough to withstand impact at velocities over 427 m/s and at yaw angles of up to 10^{o} without the nose bending. Thus the apparent weakness due to slenderness is not borne out in practice.

There is, however, a practical disadvantage of cratering weapons with elongated noses if used to attack concrete of limited thickness in that the depth of penetration may be great enough to allow the warhead to pass through the concrete. This could occur when attacking roads, for instance. Also, even if the weapon did come to rest at the correct position, the slab might be so thin that the HE was nearer the slab underside, thus cratering underneath the slab rather than on top. Such points would have to be looked at for the particular application.

The mass reductions possible with the wall-piercing weapon may be limited by the particular target. The example discussed represents a fairly hard target; softer targets could mean much smaller reductions.

5 CONCLUSIONS

It has been shown that a significant reduction in total mass can result from the use of an elongated solid nose on a warhead designed to penetrate and crater concrete. A further small reduction in mass is possible if a rocket booster is used to raise the impact velocity of a conventionally designed warhead. In the example given, the mass of the conventional weapon of 6.7 kg was reduced to 1.75 kg by using a solid nose (overall length also being reduced), and to just under 1 kg when using a rocket booster. Trials have proved that the elongated nose can survive the impact.

Reduction in mass can also, in some cases, be achieved in a warhead designed to perforate a concrete wall. In such cases, the only ways of obtaining perforation are to use a rocket booster and a solid elongated nose. A combination of the two methods may be necessary to give the minimum mass warhead.

Appendix

DESIGN BASIS OF CONCRETE PIERCING WARHEADS

Ref.1 treats the design of projectiles intended to penetrate concrete in detail, and suggests two expressions based on theory and tests as design criteria. These, when converted to SI units, become:-

$$V'_b = 2.695818 \times 10^{-7} (1 - 0.093 \sqrt{\theta}) \left(\frac{D}{c}\right)^{0.22} \left(\frac{tY^4}{DS}\right)^{1/3} \left(\frac{1}{\frac{L}{D} - 2.54}\right)^{0.5208} \qquad (1)$$

$$V'_c = 3.566124 \times 10^{-8} \left(\frac{D}{c}\right)^{0.2} \frac{1}{S^{0.75}} \left(\frac{Y \frac{t}{D}}{2 - \sin \phi_0 \left(1 - \frac{H}{M}\right)}\right)^2 \qquad (2)$$

V'_b is the impact velocity at which bending of the projectile just begins to occur, and V'_c is the impact velocity at which bulging of the HE chamber just occurs.

A necessary condition for an optimum design is that:

$$V_i = V'_b = V'_c \qquad (3)$$

where V_i is the design impact velocity.

In order to reduce the calculations necessary, the warhead configuration has been idealised as follows:

(a) Ref.1 suggests that the HE chamber should have a tapered wall over its rear half. This suggestion has been ignored. The tapering would be small in the warheads under discussion in any case. This idealisation of a parallel wall chamber cuts down the work involved considerably with only a slight effect on the end results.

(b) The existance of a fuze etc. in the warhead has been acknowledged nominally by allotting a constant volume at the rear end of the HE chamber and then designing the warhead as though this volume was filled with HE. This avoids the complication of accounting for concentrated tail masses. The end closure of the chamber has been omitted for the same reason. These assumptions are not expected to affect the conclusions of this Report significantly.

It is now simple, though tedious by hand, to design a warhead for a given crater size. Equations (1) and (2) can be written

$$\frac{V'_b}{t^{1/3}} = f(D,L,\theta,S,c,Y) \tag{4}$$

$$\frac{V'_c}{t^2} = g(D,H,M,S,c,\phi_0,Y) \quad . \tag{5}$$

The target is known, hence S and c. The warhead shape (nose ogive and chamber ogive) must be defined, giving ϕ_0 and the parameters necessary for volume calculations, and its material must be known to give Y. Knowledge of the warhead use or role should allow θ to be estimated and also the impact velocity V_i unless it is to be a variable in which case several values must be tried.

Using equations (3), (4) and (5) a value of t can be calculated for a given diameter D, chamber length L, and an estimated H/M ratio. A better H/M can then be calculated and the procedure repeated until the iteration has converged. The warhead dimensions are then known.

The penetration of the warhead into concrete is found using the empirical equation given in Ref.2 which, when converted to SI units, is:-

$$P_c = \frac{2.609842 \times 10^6}{\sqrt{S}} \frac{M}{D^2} \left(\frac{D}{c}\right)^{0.1} \left(\frac{V_i}{533.4}\right)^{97.50202/S^{1/4}} \quad . \tag{6}$$

This gives the penetration of the nose of the warhead. To calculate the crater diameter, the depth below the surface of the centre of gravity of the charge must be found. Fig.1 then gives the crater diameter; this curve has been taken from Ref.3.

To deal with solid nose warheads, it is only necessary to add the additional mass of the solid nose to the total mass M when calculating H/M or P_c, and to allow for the extra length when calculating the depth of the charge.

The size of a rocket booster necessary to give a velocity increment Δv can be estimated from

$$\Delta v = I_s \ln\left\{\frac{M + 2m}{M + m}\right\} \quad . \tag{7}$$

This is exact for vacuum conditions. The warhead mass is M and the rocket charge m. It is assumed that the rocket case etc. mass equals the charge mass, giving a total rocket mass of $2m$.

SYMBOLS

M	total warhead mass	kg
H	mass of HE plus fuze	kg
L	HE chamber cylindrical length	mm
D	warhead outside diameter	mm
ℓ	length of solid nose	mm
t	thickness of HE chamber walls	mm
Y	dynamic yield strength	N/m^2
ϕ_0	see Fig.2	degrees
θ	warhead yaw angle at impact	degrees
V_i	impact velocity	m/s
V'_b	critical velocity at which warhead just bends	m/s
V'_c	critical velocity at which bulging just occurs	m/s
P_c	penetration distance of nose into concrete	m
S	cube compressive strength of concrete	N/m^2
c	size of aggregate in concrete	mm
I_s	specific impulse	N s/kg
m	rocket charge mass	kg
Δv	velocity increment	m/s

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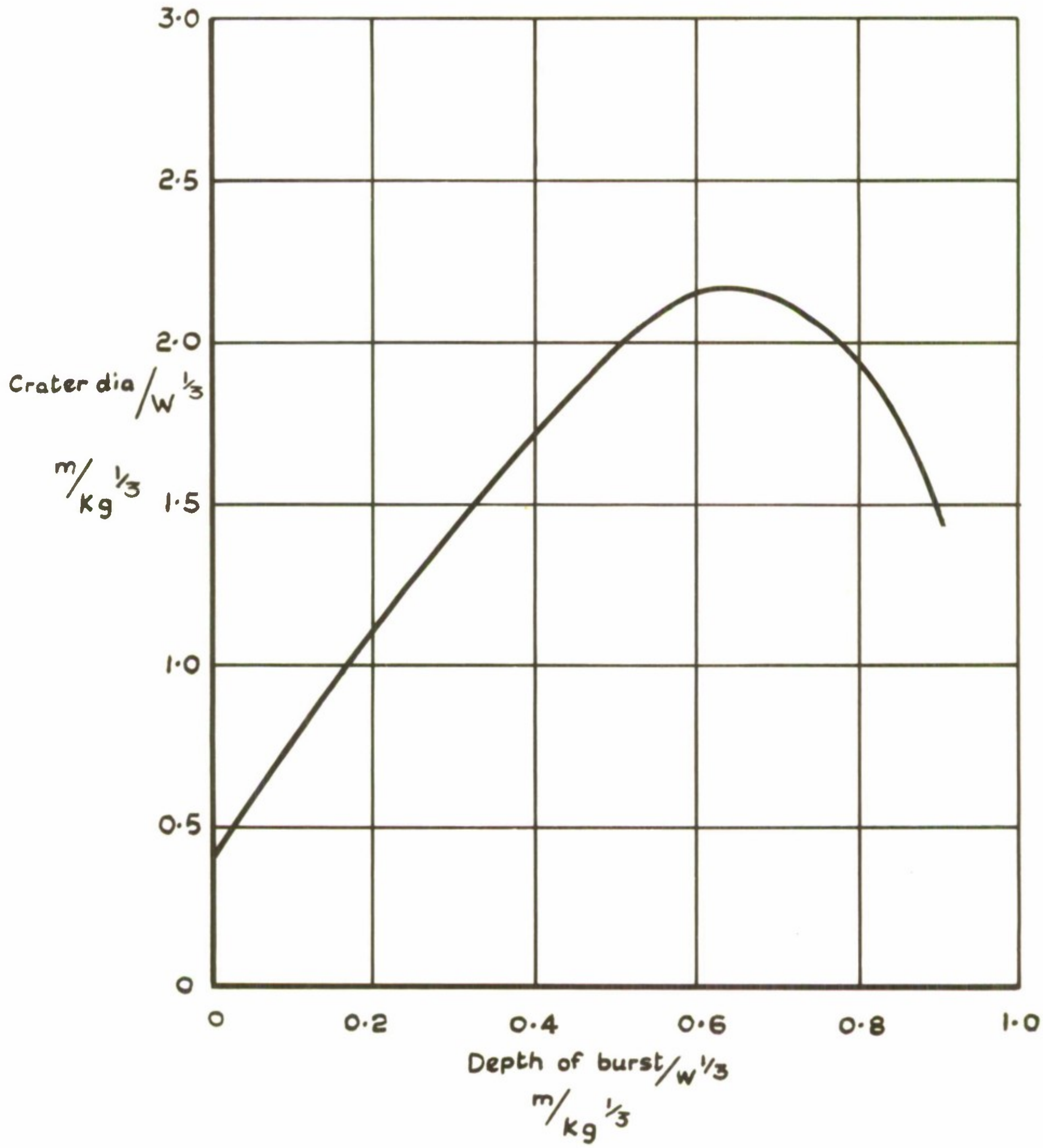

Fig. 1 Crater diameters in concrete

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Fig. 2

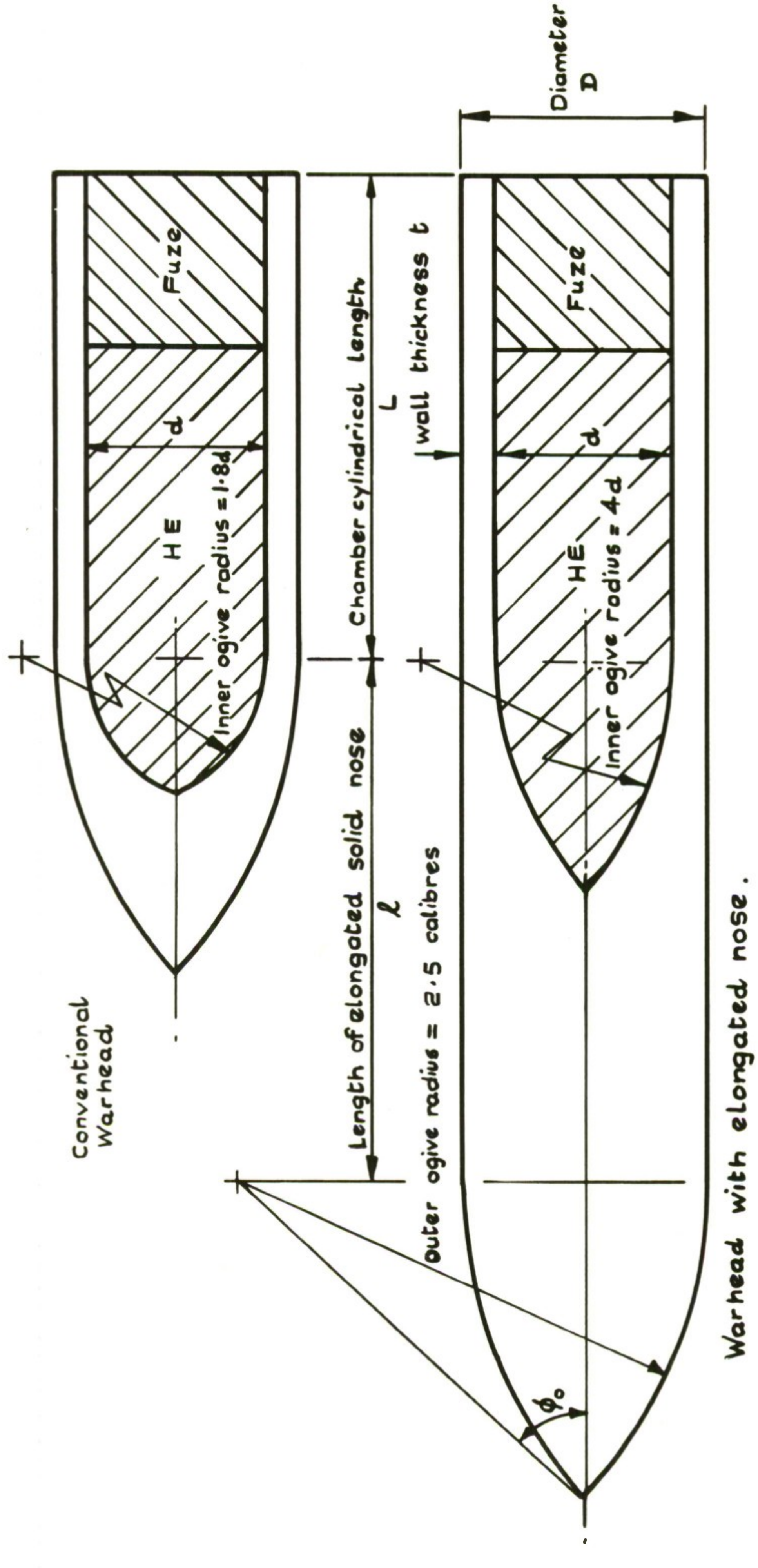

Fig 2 Warhead layout

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Total mass = rocket mass + warhead mass

V_1 = Unaided impact velocity

V_2 = Velocity required for conventional warhead to pierce wall

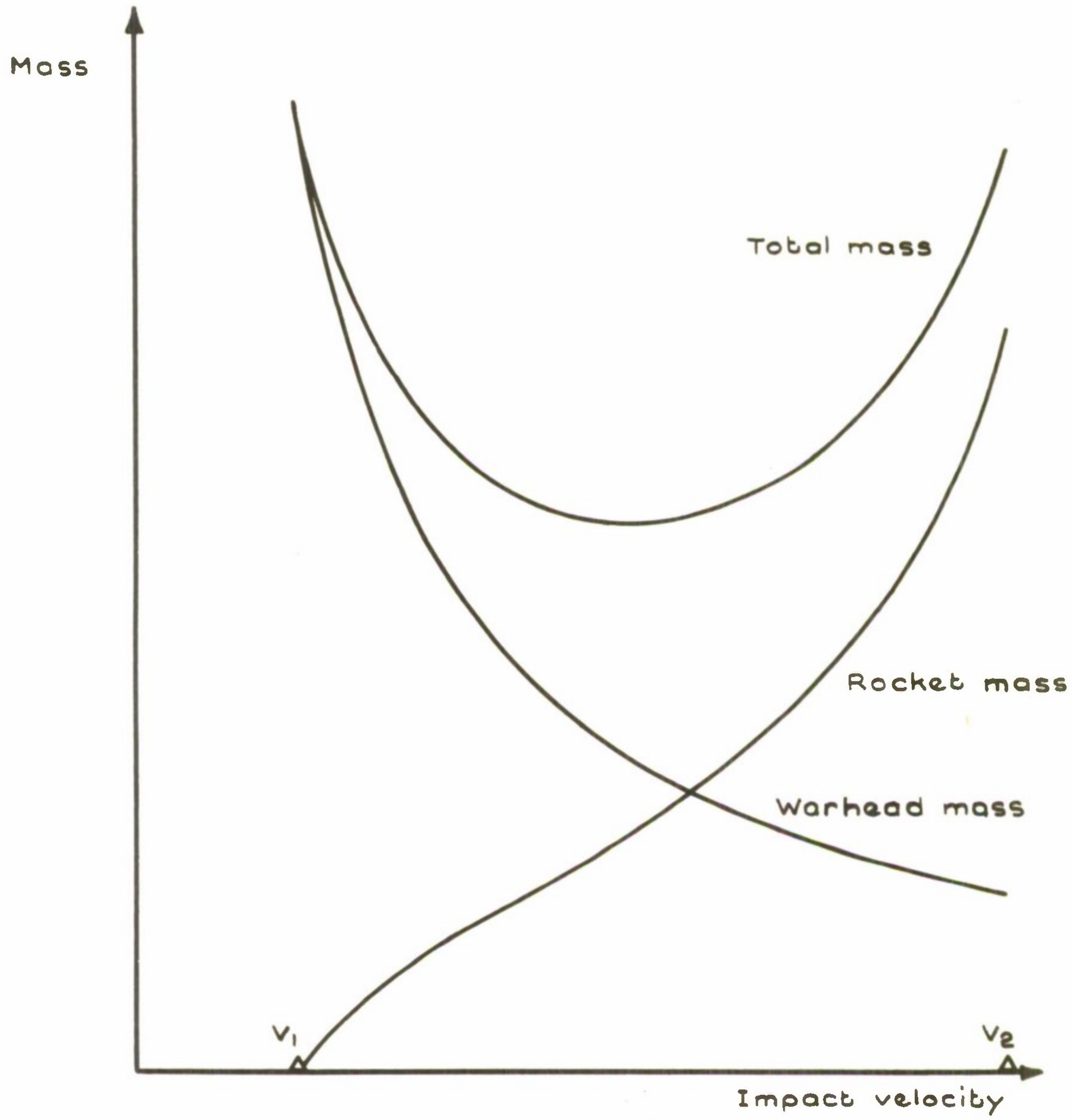

Fig. 3 Rocket boosted warheads to pierce wall

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Fig. 4

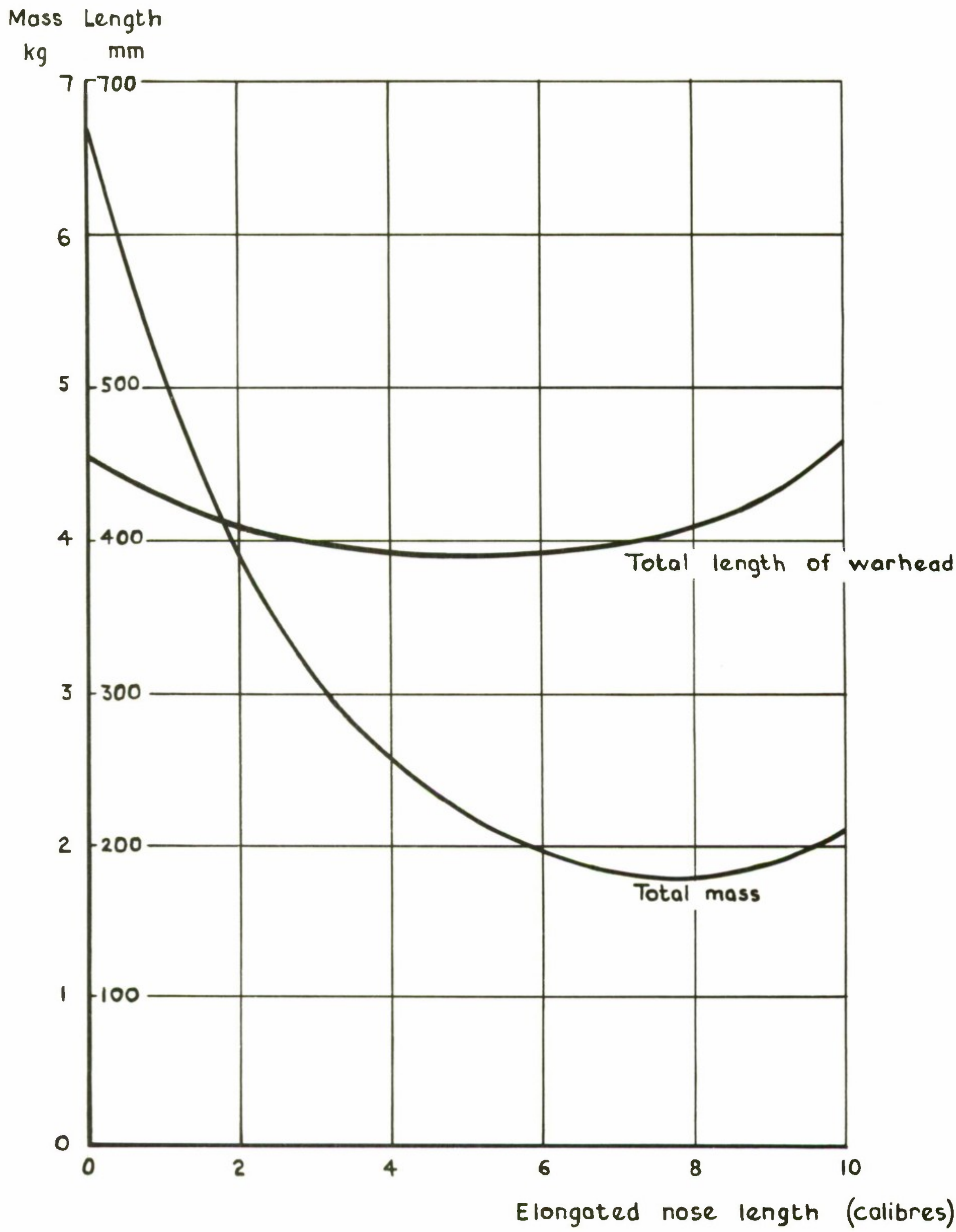

Fig. 4 Warhead mass and length for 1m crater

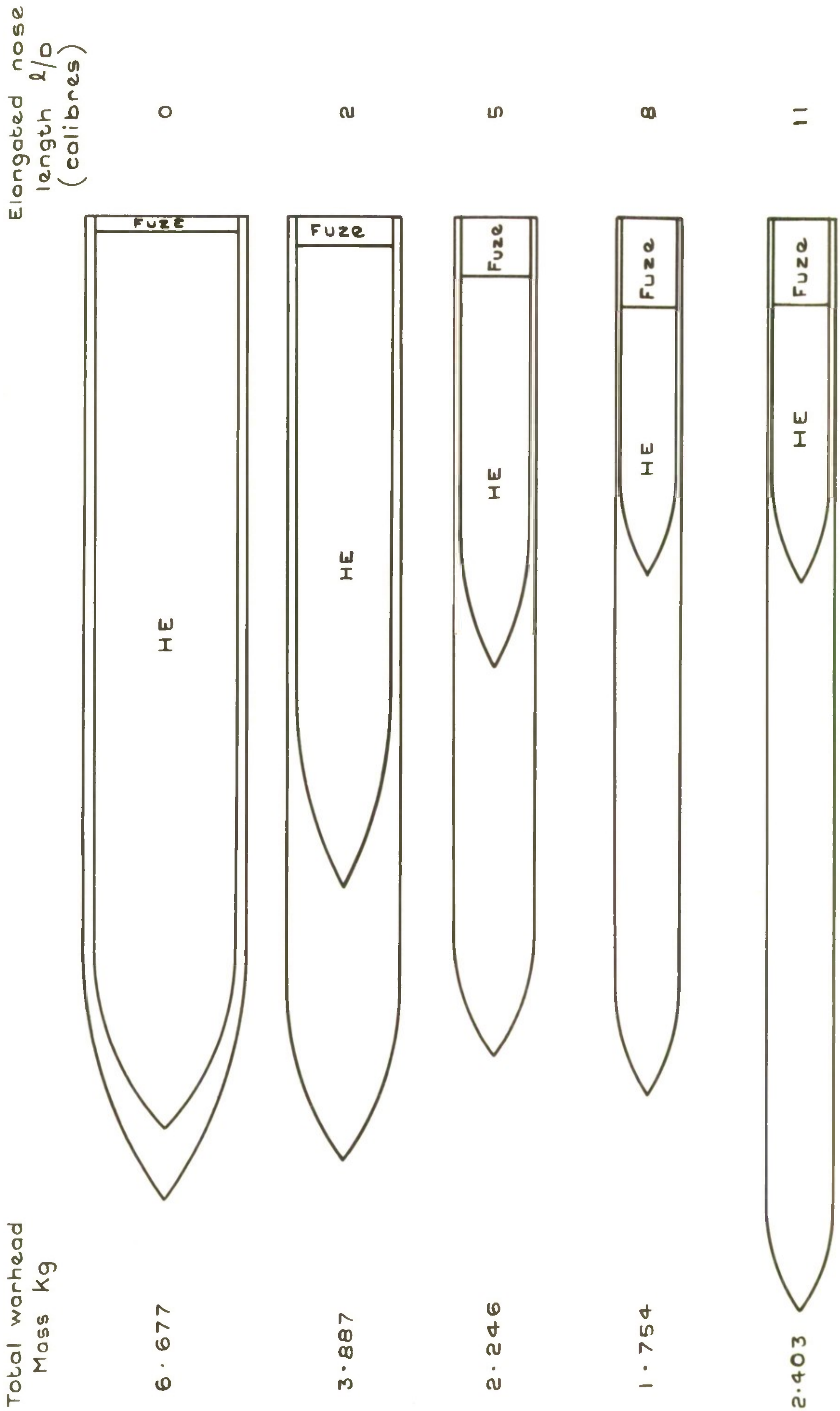

Fig. 5 5 warheads to give a 1 m crater in concrete

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